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PRINTED CIRCUIT ELEMENTS WITH APPLICATIONS TO ANTENNAS, SCATTERING, AND CIRCUITS

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13. ABSTRACT (Maximum 200 words)

The research performed during the duration of this research contract has made an impact on the analysis and design of multiport microstrip and co-planar waveguide function; the design of microstrip corporate feed and electromagnetically coupled microstrip arrays; the characteristics of aperture antennas of arbitrary shape have been extensively studied theoretically and experimentally. The effect of non-reciprocal substrates on printed antenna characteristics has been analyzed. Also, the radar cross-section of printed antennas was studied.

14. SUBJECT TERMS analysis of cavity backed aperture antenna with cover; microstrip discontinuities; CPW discontinuities; microstrip corporate feed; microstrip arrays; nonreciprocal microstrip antennas, ferrite substrates; printed antennas with coplanar waveguide feed.

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Printed Circuit Elements with Applications to Antennas, Scattering, and Circuits

Final Report

Professor N.G. Alexopoulos
Principal Investigator

October 14, 1993

U.S. Army Research Office

DAAL 03-90-G-0182

Electrical Engineering Department
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This document provides a summary of the results accomplished under U.S. Army Research Grant DAAL-03-90G-0182.

The basic theme of the research has been the modeling of printed circuits and antennas for microwave and millimeter wave applications. In this effort, novel methodologies have been developed which provide the capability to model printed antennas and circuits of the microstrip or slot type, and of arbitrary shape. The accomplishments may be summarized as follows.

(a) Modeling Multiport Microstrip And Co-Planar Waveguide Junctions.

This task included the analysis and computer algorith development for the accurate modeling of microstrip and co-planar waveguide CCOWS discontinuities. The theory modeled these discontinuities from a radiation point of view. This approach allows the quantitative determination of radiation and surface wave loss at each discontinuity, and it provides the basis for 3-D modeling in integrated circuits. The model involves an integral equation approach, which is solved numerically with the use of the method of moments for the unknown current (microstrip) or magnetic current (CPW) from which the circuit or antenna parameters are extracted.

(a.1) Corporate feed design for microstrip arrays

This is the first time that a microstrip corporate feed has been designed with rigorous theory accounting for all the physical phenomena and discontinuity effects. This microstrip corporate feed has been used as the excitation network of an electromagnetically coupled microstrip dipole array. 20dB and 30dB microstrip arrays were synthesized, built, and tested. The theoretical design procedures gave excellent results in that the array performed according to the design requirements with the first try. Figure 1 shows a generic microstrip dipole array structure coupled parasitically to an embedded microstrip corporate feed. Figure 2 is a copy of a photograph of the dipole array and the corporate feed. Figure 3 shows the comparison between theory and experiment for the radiation pattern of the design of a 20dB Dolph-Chebyshev array.

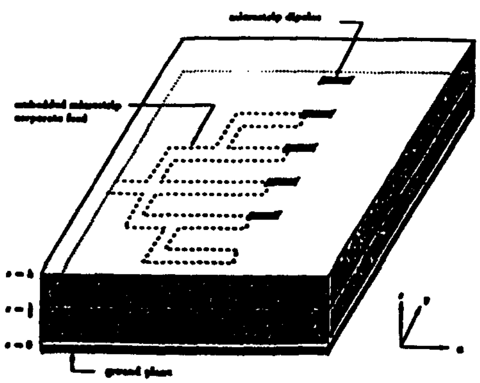
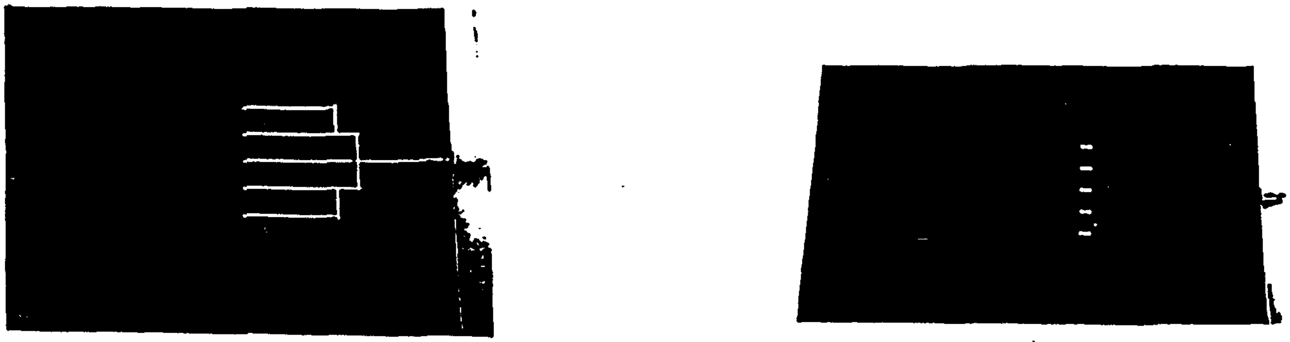


Figure 1: A linear array of microstrip dipoles fed by an embedded corporate feed.



(a) (b)

Figure 2: Fabrication of (a) the corporate feed, and (b) the dipole array on 18″ × 12″ RT/duroid boards.

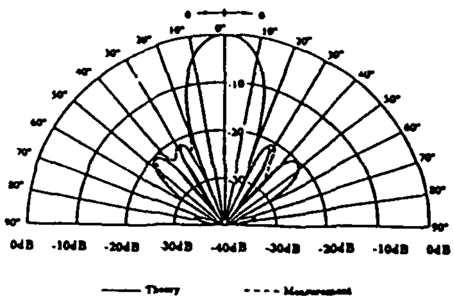


Figure 3: Comparison between the calculated and measured radiation pattern in the H-plane.

(a.2) Radiation from Printed Apertures of Arbitrary Shape

This work addresses the modeling of printed slot-type microwave antennas. We have developed a moment method code capable of efficiently and accurately modeling the aperture fields of planar conductor-backed aperture antenna elements. Input impedance and radiated fields are very accurately computed. The basis functions are linear vector-valued functions with triangular subdomains. The feed is an impressed electric current source in the plane of the aperture. This analytic method has broad application for modeling printed spiral, bow tie, log-periodic, and other relatively broadband antennas which are printed on one side of a parallel-plate region or on a semi-infinite substrate.

Several examples of arbitrary geometries are shown in the following figures. A bow-tie slot, resonant at 2.6 GHz and well matched to a 50 ohm impedance, is shown in Fig. 4. Its theoretical performance is in excellent agreement with experiment, as shown in Fig. 5. Fig. 6 displays a parametric study of the conductor-backed bow-tie input impedance as a function of half-angle alpha. As a second example, Fig. 7 shows an Archimedian monofilar spiral antenna. Its theoretical input impedance, shown in Fig. 8, is also in excellent agreement with experimental data. The broadside axial ratio shown in Fig. 9 is also accurately predicted.

We believe that this electromagnetic modeling effort affords an unprecedented level of accuracy and flexibility in modeling a wide class of printed antennas.

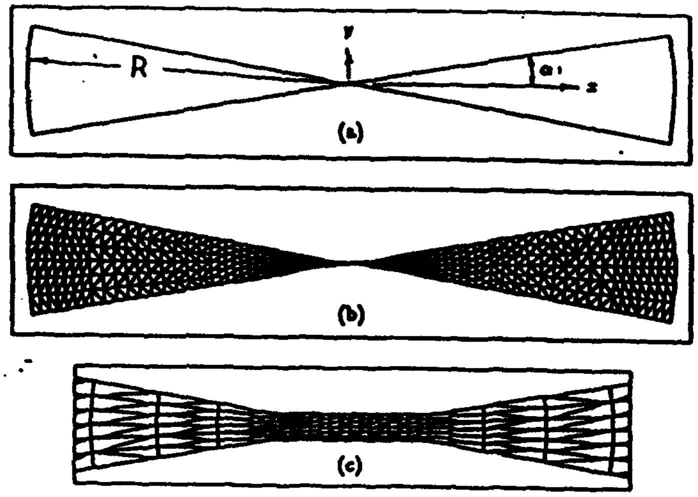


Figure 4: Grid used for the 10° bow-tie slot antenna: (a) outline drawing, $\alpha = 10°$; (b) a view of the entire triangulated aperture; (c) a detailed view of the feed region.

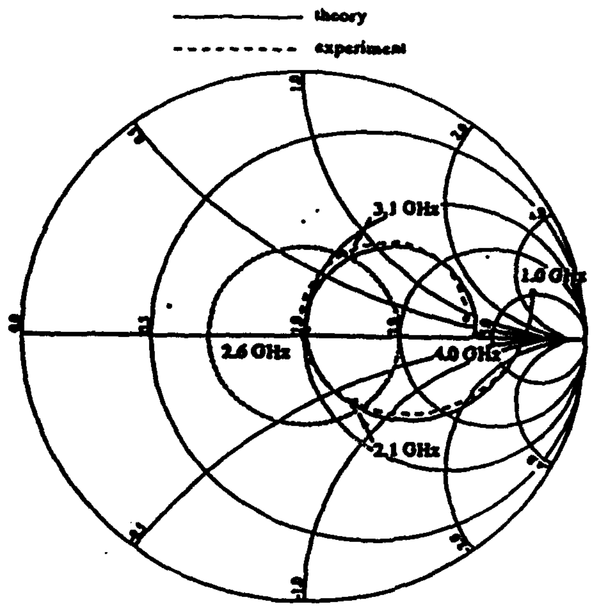


Figure 5: A comparison of theoretical and experimental input impedance for a 10° bow-tie slot antenna; reference impedance = 50 ohms, b = 1000 mils, w = 20 mils, R = 2000 mils, $\sigma_{th} = 10$, $\epsilon_r = 1.08$.

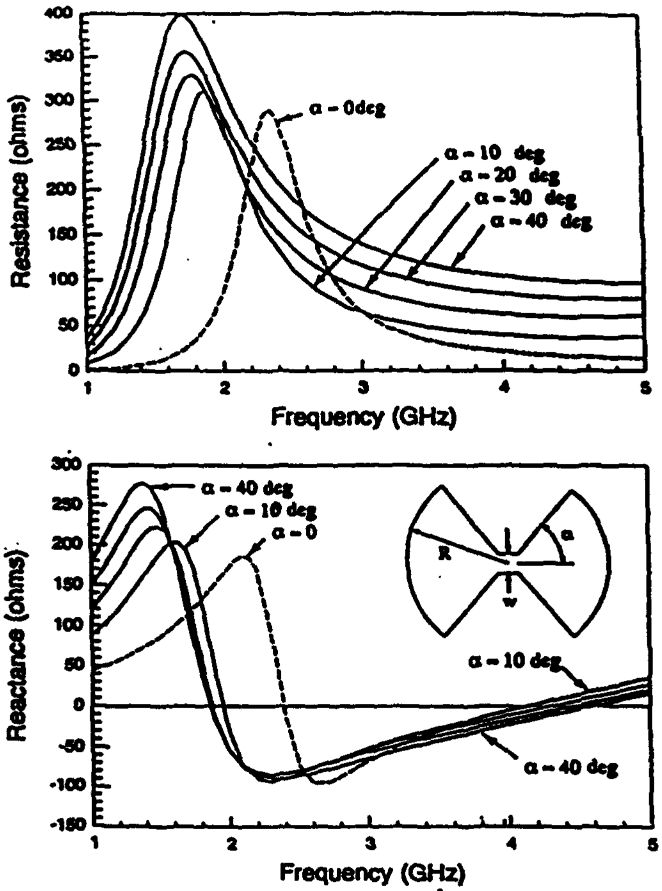


Figure 6: Input impedance for a conductor-backed bow-tie slot antenna: $\epsilon = 2.2$, b = 500 mils, w = 20 mils, R = 1000 mils, $\sigma_{th} = 10$.

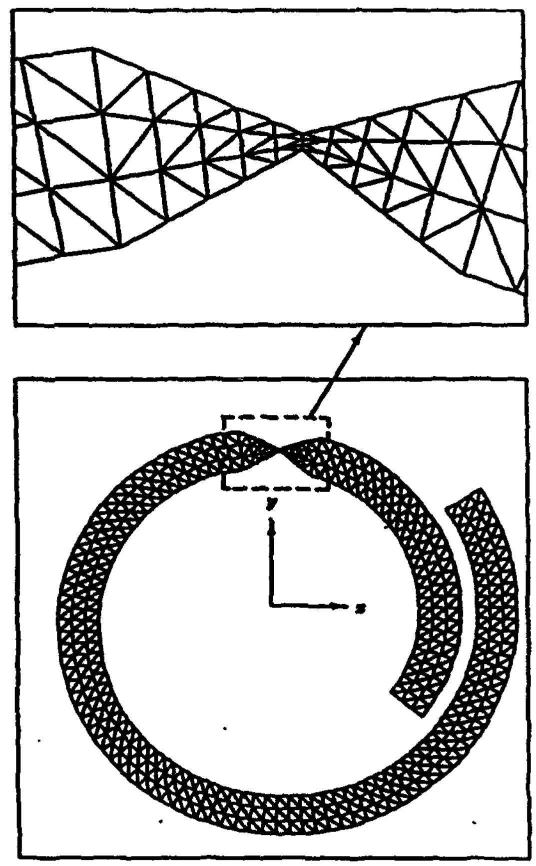


Figure 7: Grid for the monofilar spiral containing 989 interior edges.

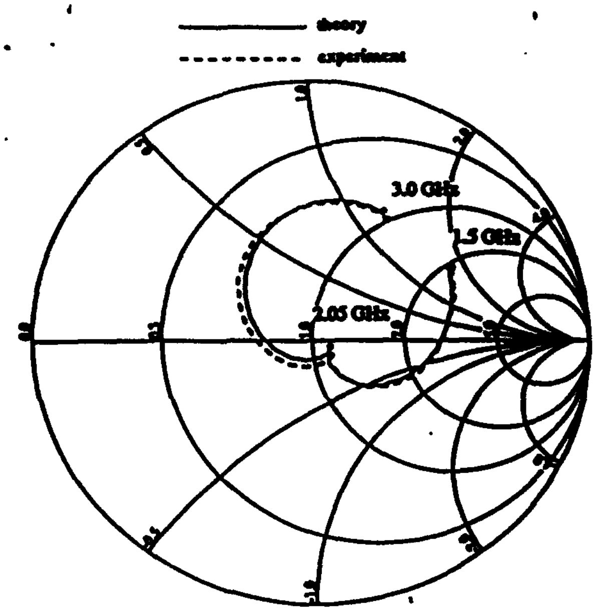


Figure 8: Input impedance of the monofilar spiral referenced to 100 ohms: $\epsilon_r = 1.08$, $b = 1000$ mils, $w = 254$ mils, $\theta_{st} = 5.81\pi$, $\theta_{end} = 8.188\pi$, $a = 57.5$ mils, $\Delta = 45$ mils.

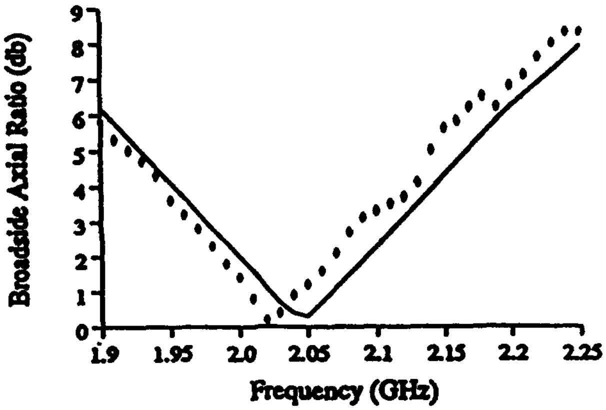


Figure 9: Broadside axial ratio versus freqwuency for the monofilar spiral: − theory, ◇ ◇ ◇ ◇ experiment, $\epsilon_r = 1.08$, $b = 1000$ mils, $w = 254$ mils, $\theta_{st} = 5.81\pi$, $\theta_{end} = 8.188\pi$, $a = 57.5$ mils, $\Delta = 45$ mils.

(a.3) Microstrip Discontinuity and Junction Characterization and Equivalent Circuits

Rigorous characterization and extraction of the scattering parameters of microstrip discontinuities and junctions has been achieved. A quantitative delineation of radiation and surface wave loss at microstrip discontinuities has been demonstrated. Precise knowledge of radiation and surface wave loss enables the derivation of highl: accurate equivalent circuits which are quite simple and can be used for user friendly software. This approach is needed to develop user friendly software for microwave circuits comparable to SPICE. An example of this approach is shown in Figures 10 – 13 for the open end microstrip discontinuity.

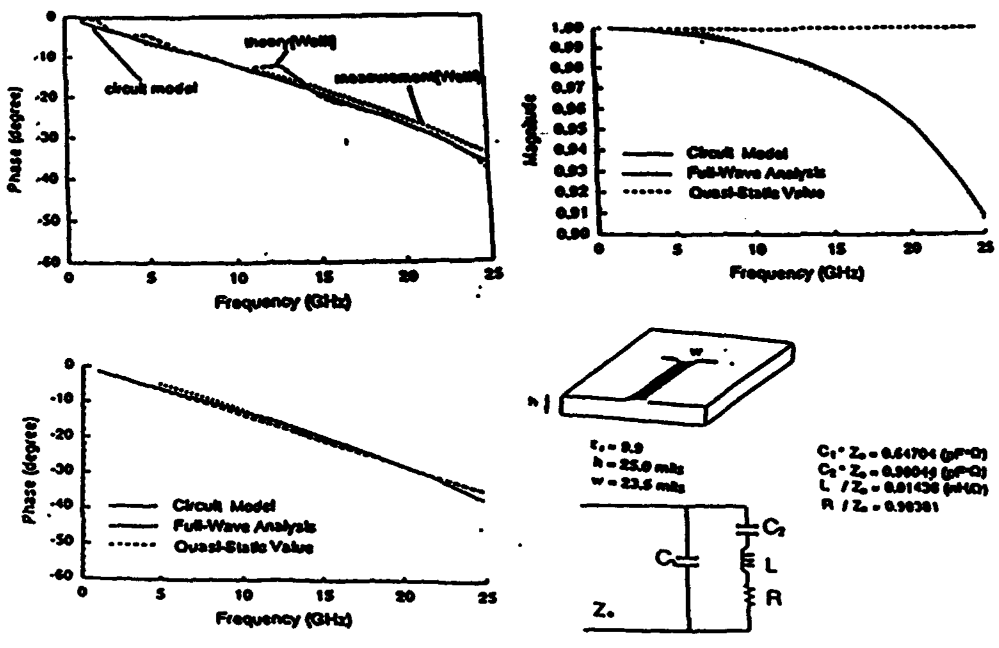


Figure 10 – 13: Equivalent circuit for open end discontinuity

The following papers have been published under this task:

1. T.S. Horng, H.-Y. Yang, and N.G. Alexopoulos, "Corporate Feed Design for Microstrip Arrays", *Proceedings of the Second International Conference on Electromagnetics in Aerospace Applications*, pp. 409-411, September 17-20, 1991, Politecnico Di Torino, Italy

2. T.-S. Horng, C.-C. Wang, and N.G. Alexopoulos, "Microstrip Circuit Design Using Neural Networks", *1993 International IEEE Microwave Theory and Techniques Symposium Digest*, Atlanta, Georgia

3. T.-S. Horng and N.G. Alexopoulos, "Corporate Feed Design for Microstrip Arrays", *IEEE Transactions on Antennas and Propagation*, December 1993.

4. T.S. Horng, N.G. Alexopoulos, S.-C. Wu, and H.-Y. Yang, "Full-Wave Spectral-Domain Analysis for Open Microstrip Discontinuities of Arbitrary Shape Including Radiation and Surface-Wave Losses" (Invited Paper), *International Journal of Microwave and Millimeter-Wave Computer-Aided Engineering*, vol. 2, no. 4, pp. 224-240, 1992.

5. W.E. McKinzie III, *Electromagnetic Modeling of Conductor-Backed Aperture Antennas and Circuits of Aribitrary Shape*, Ph.D. Dissertation, UCLA 1992.

(b) Magnetodielectric Substrate Effects on the Radar Cross Section of Printed Antennas

The scattering cross section of microstrip dipoles was examined. The primary emphasis was to demonstrate the effects of surface waves on the scattering cross section, and to provide a simple physical understanding of the surface wave mechanism. The electric field integral equation (EFIE) was solved in the spatial domain using the method of moments. Special techniques were used to speed up the evaluation of the Sommerfeld integrals. The radar cross section (RCS) for several microstrip dipole configurations was presented. The mechanism for generation of surface waves plays a major role in the scattering behavior of the dipoles, and a physically intuitive interpretaiton of this mechanism was used to successfully explain the pattern structure. Generally, magnetodielectric substrates with and without loss were considered.

The following refereed journal publication resulted from this task:

G.E. Antilla and N.G. Alexopoulos, "Surface Wave and Related Effects on the RCS of Microstrip Dipoles Printed on Magnetodielectric Substrates", *IEEE Transactions on Antennas and Propagation*, vol. 39, no. 12, pp. 1707-1715, December 1991.

(c) Microstrip Fed Antennas

The aim of this task was to provide highly accurate design for microstrip fed microstrip antennas. In this particular case, the contribuiton to radiation, and particularly to antenna cross-polarization, by the microstrip line was delineated. Experimental and theoretical results agreed very well.

The following refereed journal publication resulted from this task:

S.-C. Wu, N.G. Alexopoulos, and O. Fordham, "Feeding structure contribution to radiation by patch antennas with rectangular boundaries", *IEEE Transactions on Antennas and Propagation*, vol. 40, no. 10, pp. 1245-1249, October 1992.

(d) Non-reciprocal Microstrip Antennas

In this particular case, a microstrip antenna (strip dipole) was excited parasitically by a microstrip transmission line embedded inside the substrate. A substrate-superstrate structure was investigated, wherein one of the layers may be a non-reciprocal ferrite layer, while the other one may be an insulator or semiconductor. The effect of the non-reciprocal layer in scanning the microstrip antenna beam was demonstrated.

The following journal paper has been submitted to the *IEEE Transactions on Antennas and Propagation*, and is currently under review:

Irene Y. Hsia and N.G. Alexopoulos, "Electromagnetically Coupled Dipole Antennas in Non-reciprocal Microstrip".

(e) Co-planar Waveguide Fed Aperture Antennas

Slot-type antennas were examined from the excitation point of view. A co-planar waveguide feed structure was designed, and various aperture-type (slot) antennas were excited by it. Excellent agreement was obtained between theory and experiment.

The following journal paper has been submitted to the *IEEE Transactions on Antennas and Propagation*, and is currently under review:

H.-C. Liu, T.-S. Horng, and N.G. Alexopoulos, "Radiation of Printed Antennas with a Coplanar Waveguide Feed".

(f) Cavity-Backed Microstrip or Slot Antennas

This research task involved the examination of radiation by, as well as the radar crosssection of, cavity-backed slot or microstrip antennas with a superstrate layer:

The following journal paper has been submitted to the *IEEE Transactions on Antennas and Propagation*, and is currently under review:

J.-Y. Lee, T.-S. Horng, and N.G. Alexopoulos, "Analysis of Cavity-Backed Aperture Antenna with a Cover (Superstrate)".

(g)

(i) The following individuals have participated in the research performed under this grant:

William McKinzie
Tzyy Sheng Horng
Shih-Chang Wu
Pyotr Y. Ufimtsev
G.E. Antilla
Irene Y. Hsia
James Chi
Ching-Lung Chen
Ming-Ju Tsai

(ii) There are no reportable inventions.